(12) UK Patent Application (19) GB (11) 2 306 694 (13) A

(43) Date of A Publication 07.05.1997

(21) Application No 9521158.7

(22) Date of Filing 17.10.1995

(71) Applicant(s)
Northern Telecom Limited

(Incorporated in Canada - Quebec)

World Trade Center of Montreal, 380 St Antoine Street West,8th Floor, Montreal, Quebec H2Y 3Y4, Canada

(72) Inventor(s)
Terry Victor Clapp

(74) Agent and/or Address for Service
S F Laurence
Northern Telecom Europe Limited, West Road, HARLOW, Essex, CM20 2SH, United Kingdom

(51) INT CL^6
G02B 6/10

(52) UK CL (Edition O)
G2J JGDA JGDB

(56) Documents Cited
WO 91/10931 A1 **US 5134681 A**

(58) Field of Search
UK CL (Edition N) **G2J JGDA JGDB**
INT CL^6 **G02B**

(54) **Strip-loaded planar optical waveguide**

(57) A strip-loaded planar optical waveguide is formed by a strip 11a, eg 30-70nm thick of e.g. silicon nitride on one face of a (e.g. 5μm thick) dielectric guide layer 12 sandwiched between a silica substrate 10 and a cladding layer 13 having a refractive index matching that of silica.

The guide layer 12 may be silica doped with phosphorus and/or germania. The strips 11a may be configured as tapers (30, Fig.3) for coupling a linear array of semiconductor lasers into a fibre ribbon, or Y-splitters (40, Fig.4). The strip 11a may have crenellated sides (50, Fig.5).

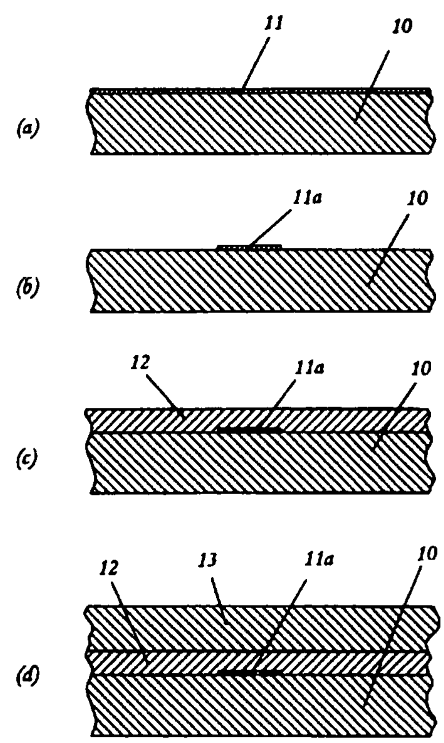

Fig. 1.

GB 2 306 694 A

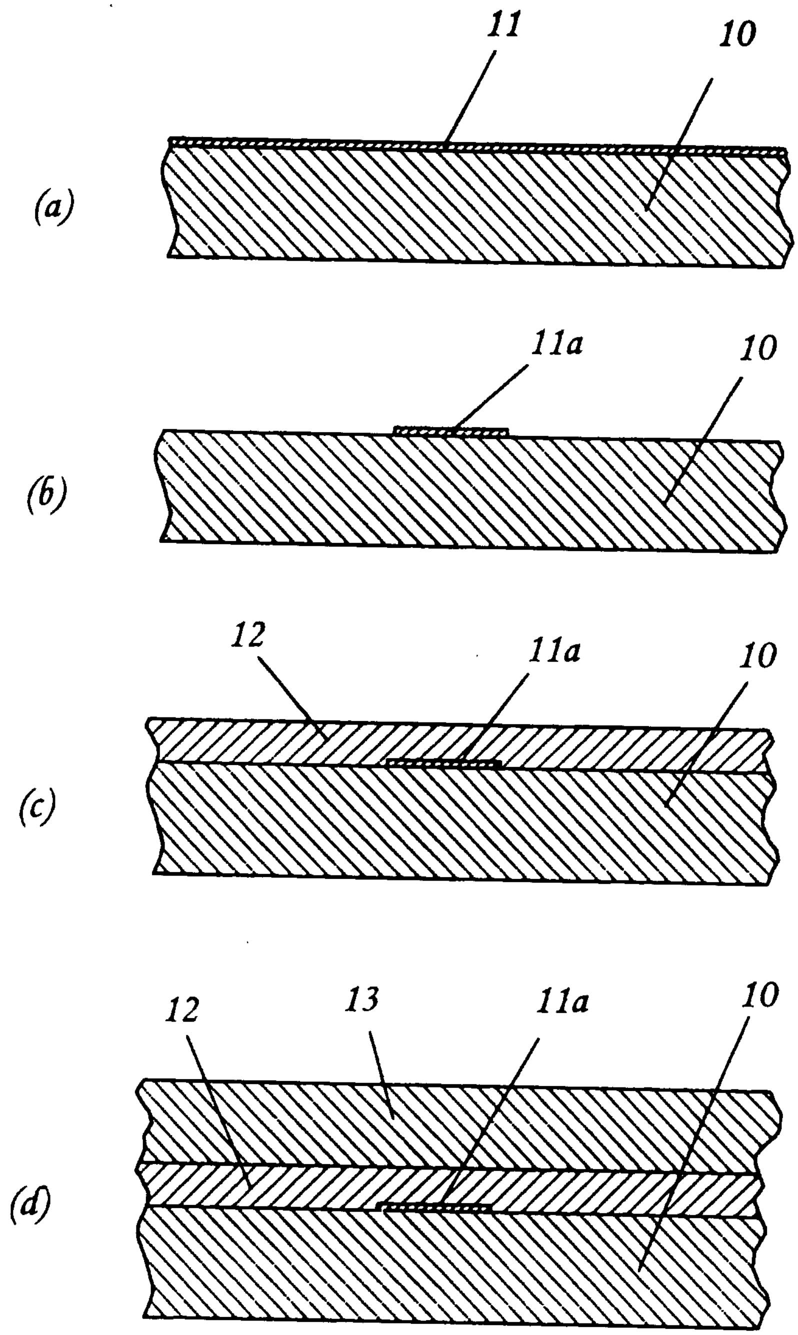

Fig. 1.

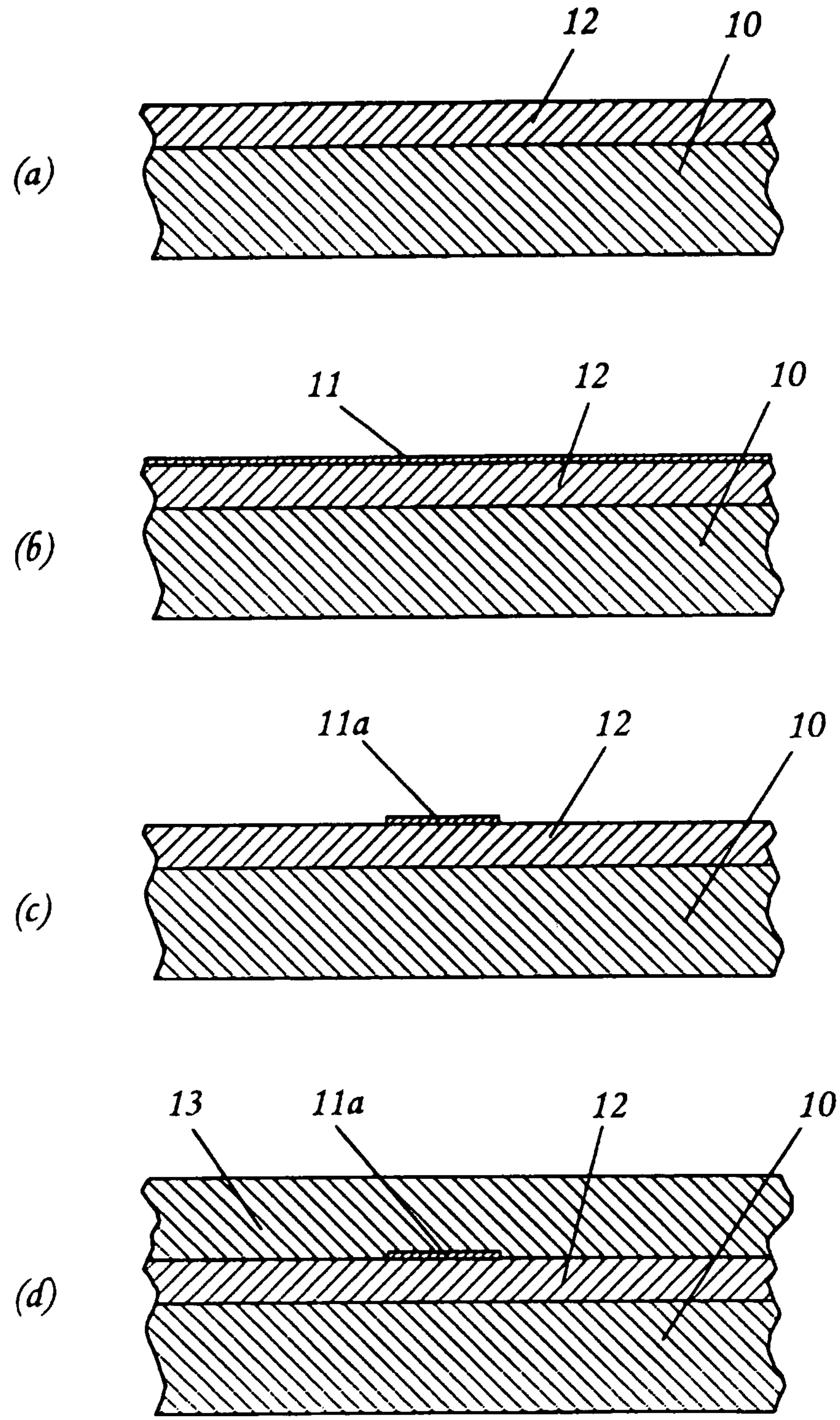

Fig. 2.

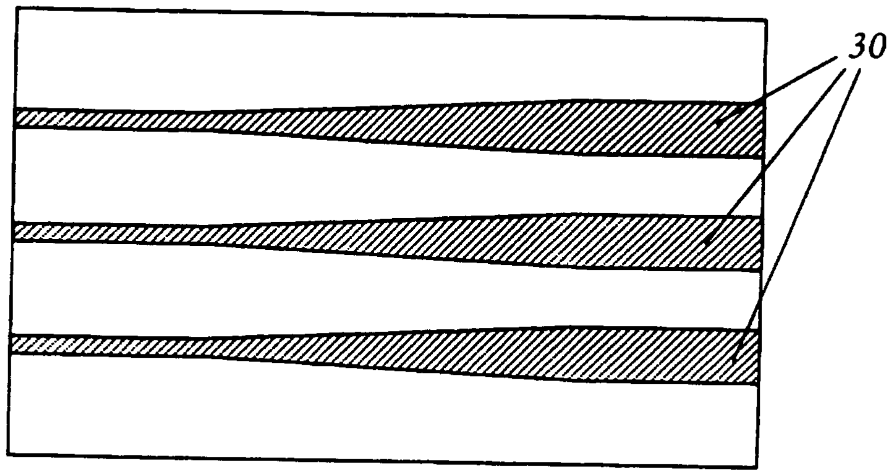

Fig. 3.

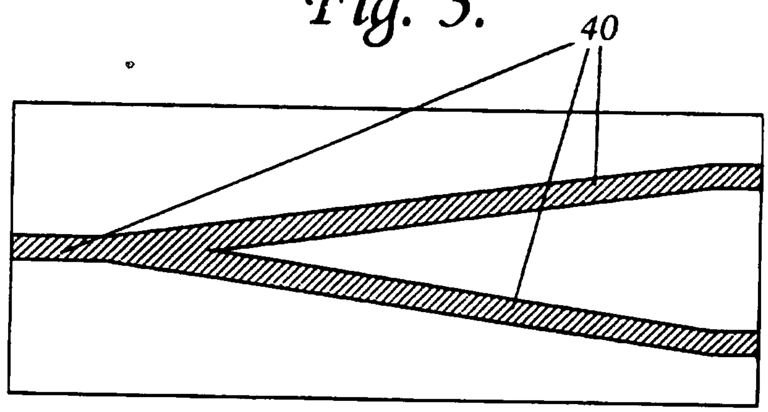

Fig. 4.

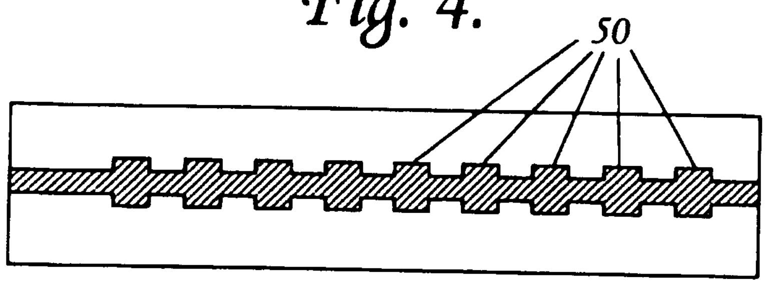

Fig. 5.

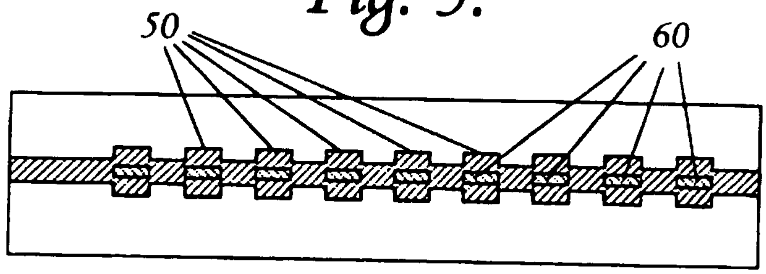

Fig. 6.

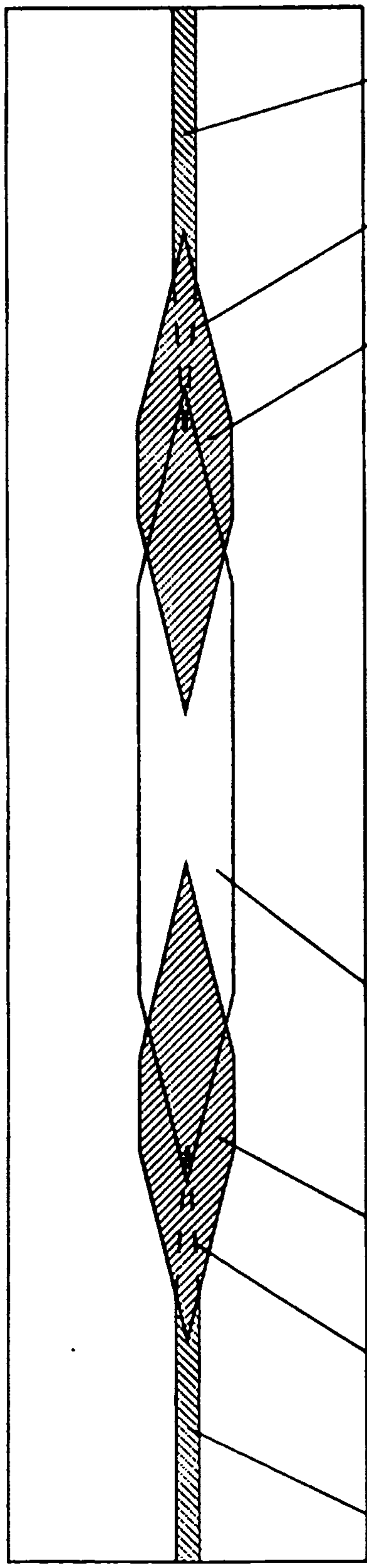

Fig. 7.

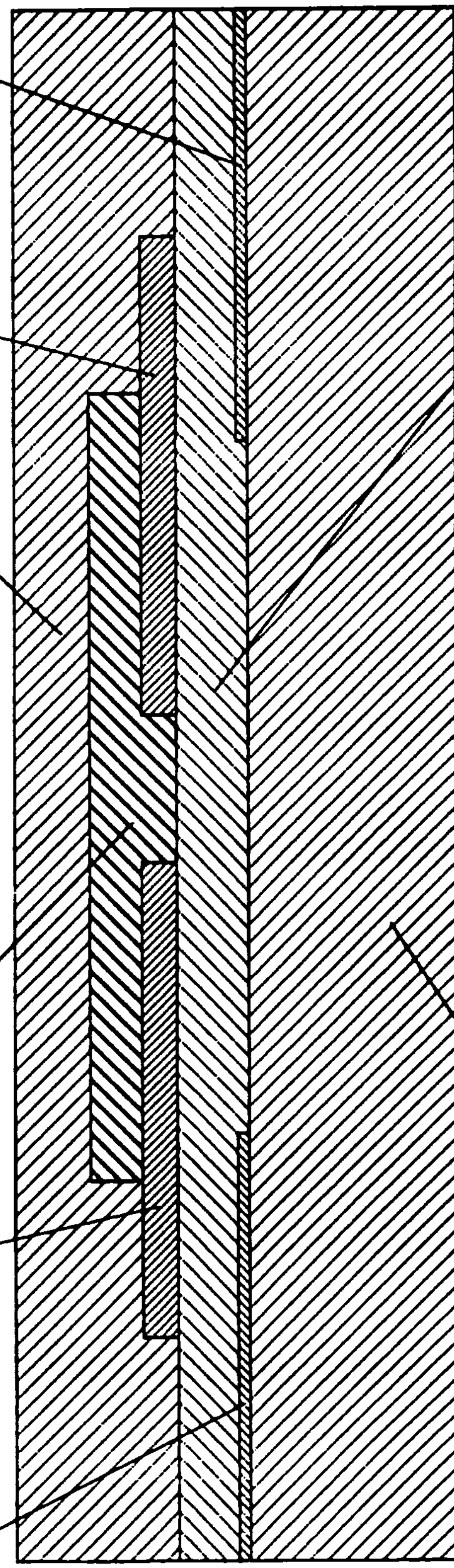

Fig. 8.

2306694

Optical Waveguide Devices

Optical waveguides are typically formed as optical fibres, which are physically flexible, or they are formed on or in substantially rigid structures where the waveguide or waveguides typically extend in a single plane. The latter are often referred to as 'planar waveguides'. A particularly basic form of planar waveguide is the slab waveguide which comprises a semi-infinite guiding layer of core material bounded on both major surfaces by material of lower refractive index. The interfaces between the major surfaces of the guiding layer and the lower refractive index materials bounding those surfaces provide optical confinement (waveguiding effect) in a direction normal to the plane of the layer for light launched into an edge of the guide layer, but the structure provides no waveguiding effect to confine the lateral spread of the light within the layer.

If a lateral waveguiding effect is also wanted, then one way of achieving this is to replace the semi-infinite guiding layer of the slab waveguide with a ribbon of dielectric material surrounded on all sides by material of lower refractive index. Such a waveguide will hereinafter be referred to as a 'planar ribbon waveguide'. One method by which a planar ribbon waveguide can be produced is described in United States Patent Specification 3 806 223, and comprises depositing a ribbon of material of a particular refractive index upon the surface of a layer of material of a lower refractive index, and then coating the exposed surfaces of the ribbon with a cladding layer of material which similarly has a refractive index lower than that of the ribbon. Instead of depositing the higher refractive index material of the ribbon as a ribbon, it may be deposited in the form of a layer that is subsequently patterned and selectively etched to produce the ribbon prior to the deposition of the cladding layer of low refractive index material.

An alternative way of providing a lateral waveguiding effect is to leave the planar guide layer intact, and to form one or more strips of material on either or both of its major surfaces which is of higher refractive index than that of the material bounding that surface into which the strips protrude. These strips may for instance be made of material having the same refractive index as that of the guide layer, and may indeed be formed of the same material as that of the guide layer. This type of waveguide is known as a 'strip-loaded planar waveguide'.

Strip-loaded planar waveguides are to be found in a number of types of double-heterostructure semiconductor laser devices. A basic slab waveguide structure is formed by a simple planar arrangement of double-heterostructure layers, but for many applications a lateral waveguiding effect is required for improved optical confinement. A strip-loaded planar waveguide structure laser, of a type more commonly known as a ridge structure laser, is for instance described in United States Patent Specification 4 728 628. In this structure a composite guide layer comprising three substructure layers of InGaAsP, is grown upon the surface of a lower refractive index substrate of InP. On top of the guide layer, is a strip of InP which has a higher refractive index than that of the air on either side of the strip. (In this instance the height of the strip is so great in relation to its refractive index and that of the guide layer that there is no need for the top of the strip to be covered with lower refractive index material.) Another example is the Inverted Rib Waveguide (IRW) laser, as described for instance in United Kingdom Patent Specification 1 577 250, where a channel is formed in low refractive index substrate material prior to the growth of a composite guiding layer that both covers the substrate and fills in the channel so as to form an inverted rib of higher index material protruding into the lower refractive index material of the substrate.

In semiconductor laser design lateral waveguiding may alternatively be provided by buried-heterostructure configurations, these being specific examples of planar ribbon waveguides. In planar waveguides constructed in non-semiconductor material, such as silica, both strip-loaded and ribbon types of planar waveguide are described in the

literature. Thus a strip-loaded planar waveguide is described by C H Henry et al in a paper entitled, 'Glass Waveguides on Silicon for Hybrid Optical Packaging' (J Lightwave Technology Vol 7, No. 10 pages 1530-9), in which a layer of silicon nitride between two layers of silica. In the same paper the authors subsequently also describe a ribbon-type planar waveguide in which a ribbon of phosphorus-doped silica is sandwiched between two layers of lower refractive index glass. In the case of the manufacture of such ribbon-type planar waveguides, the ribbon is typically created by depositing a layer of the core class material upon a substrate of lower refractive index cladding glass. This core glass layer which is typically about 5μm thick, is then patterned using thin film lithography before deep reactive ion etching is employed to remove unwanted core glass material to leave behind the desired configuration of ribbon(s). Then the substrate, together with its pattern of ribbons is coated with a further layer of glass whose refractive index is less than that of the core glass material and typically has a refractive index matched with that of the underlying cladding glass substrate.

Satisfactory planar ribbon waveguides can with care be made in dielectric materials by this approach, but its general application, particularly to the creation of intricate waveguide structures, is limited on the one hand by the degradation of profile encountered when reactive ion etching to such depths, and on the other hand by the difficulties in ensuring that the cladding layer completely fills all the corners created by the deep reactive ion etching.

The present invention is directed to a method of planar waveguide device creation in which these problems are significantly ameliorated.

According to the present invention there is provided a strip-loaded optical waveguide device having a substantially planar dielectric guide layer on one major surface of which is provided one or more waveguide defining loading strips of low profile compared with the thickness of the guide layer and of higher refractive index than that of the guide layer, wherein the two major surfaces of the guide layer, together with the or

each loading strip, are bounded by dielectric material of lower refractive index than that of the guide layer.

As explained above, strip loaded planar waveguides are known, however that strip-loading has previously comprised material whose refractive index is not greater than that of the guide layer itself. Dielectric planar waveguides are typically constructed in silica, and have a guide layer of silicon nitride or of silica that has been doped to raise the refractive index slightly above that of undoped silica. Silica has a refractive index that is particularly low in comparison with most other oxide-based glasses, and other materials exist, such as silicon nitride, which has a high refractive index compared with most oxide glasses. It is thus possible to provide quite a large refractive index step between a doped silica guide layer and a loading-strip. Accordingly a loading-strip can be used to provide an adequate lateral waveguiding effect, even though it be then compared with the thickness of the guide layer that it is loading. Typically, but not necessarily, the configuration of the loading-strip may be such as to leave the bulk of the propagating optical energy propagating in the guide layer, with only a small proportion propagating in the loading-strip.

One advantage of a low-profile loading-strip is that it can be produced from selective etching of a layer with good replication of mask contour. Such a loading-strip may for instance comprise a layer of silicon nitride having a thickness typically in the range 30 to 70 nm, which is comparable in thickness to what is used in standard semiconductor device processing. At these sorts of thickness, photolithography and reactive ion etching can be used to generate shapes in such material which replicate mask shapes with a high degree of accuracy. Another advantage is that, with these sorts of thicknesses, there is little problem in ensuring that a covering layer fills in the corners without leaving significant voids.

The invention also provides a method of making a strip-loaded optical waveguide device including the steps of;

coating a major surface of a dielectric substrate layer with a waveguide configuration defining layer;

patterning said waveguide configuration defining layer and removing portions thereof to define one or more substantially isolated strips of material of the waveguide configuration defining layer;

coating the strip-coated surface of the substrate layer with a dielectric guide layer; and

coating the guide layer with a dielectric cladding layer;

wherein the thickness of the waveguide configuration defining layer is small compared with the thickness of the guide layer; and

wherein the refractive index of this waveguide configuration defining layer is greater than that of the guide layer which, in turn, is greater than that of both the substrate layer and the cladding layer.

Generally it will be preferred to have this strip-loading sandwiched between the substrate and the guide layer because the top surface of the substrate layer is likely to be flatter than that of a layer deposited upon it. In certain circumstances it may be desirable instead to have the strip-loading sandwiched between the guide and cladding layers.

Accordingly, the invention further provides a method of making a strip-loaded optical waveguide device including the steps of;

coating a major surface of a dielectric substrate layer with a dielectric guide layer;

coating the guide layer with a waveguide configuration defining layer;

patterning said waveguide configuration defining layer and removing portions thereof to define one or more substantially isolated strips of material of the waveguide configuration defining layer; and

coating the guide layer and its one or more strips with a dielectric cladding layer;

wherein the thickness of the waveguide configuration defining layer is small compared with the thickness of the guide layer; and

wherein the refractive index of the waveguide configuration defining layer is greater than that of the guide layer which, in turn is greater than that of both the substrate layer and the cladding layer

There follows a description of the manufacture of strip-loaded dielectric waveguide devices embodying the present invention in preferred forms. The description refers to the accompanying drawings, in which:-

Figures 1(a) to (d) and 2(a) to (d) depict schematic cross-sections of substrates during successive stages in the manufacture of a strip-loaded planar waveguide on each of two substrates, respectively by different methods of manufacture,

Figures 3 to 6 schematically depict illustrative examples of different types of strip-loaded planar waveguide device made by either of the methods of Figures 1 and 2, and

Figures 7 and 8 schematically depict respectively a plan view and a longitudinal sectional view of a device in which light is coupled between first and second strip-loaded planar waveguides via an overlying waveguide.

Referring in the first instance to Figure 1, a high quality silica substrate 10, typically 0.5 or 1.0mm thick, is coated with a thin layer 11 (Figure 1a), typically in the range 30 to 70 nm thick, of high refractive index material such as silicon nitride. This layer may for instance comprise a 50 nm silicon nitride layer deposited by low pressure CVD using conventional semiconductor processing. The layer 11 is patterned using conventional thin-film lithography, and selectively etched to delineate one or more strips 11a (Figure 1b). The etching of silicon nitride may conveniently be accomplished using reactive ion etching. The substrate 10, together with its ribbons 11a, is then coated with a thicker guide layer 12 of silica doped to raise its refractive index slightly above that of the silica substrate. In the case of silicon nitride ribbons between 3 and 5 μm wide, this guide layer may for example be about 5 μm thick, and have a phosphorus and/or germania doping providing a

refractive index about 7×10^{-3} higher than that of silica. This layer 12 is deposited by plasma-enhanced CVD, and preferably is consolidated, either in a furnace or using a rapid thermal annealer, before the deposition of a cladding layer 13, also deposited by plasma-enhanced CVD, and also consolidated after deposition. This cladding layer 13 has a refractive index that is less than that of the guide layer. Typically its refractive index matches that of the silica substrate 10, and it may itself be made either of undoped silica or compensation doped silica, for instance silica doped with phosphorus and/or germania, and with boron. Generally such a cladding layer is at least 10 μm thick.

Figures 2a to 2d depict an equivalent sequence of stages in the alternative process in which the silicon nitride layer 11 is deposited after the deposition of the core layer 12 instead of beforehand.

The small thickness of the strip-loading stripes 11a in comparison with the full thickness of the guide layer 12 significantly facilitates the construction of waveguides to close dimensional tolerances as compared with their construction in ribbon-type format that requires etching through the thickness of the guide layer rather than merely through the strip-loading layer 11. This facilitates the construction of spatial transformers in planar waveguide format which will convert the modal power distribution in a mode from one configuration at one end of the waveguide to a different configuration at the other. In such a transformer one end may have a spatial power distribution of the fundamental mode close to that emitted by a semiconductor laser and the other end a power distribution close to that propagating in conventional single mode optical fibre. Figure 3 depicts a strip-loaded planar waveguide structure in which the strips 11a are configured as tapers 30 for coupling the output of a linear array of semiconductor lasers (not shown) at one side of the structure into the ends of a fibre ribbon (not shown) at the other side. It similarly facilitates the construction of low-loss Y-splitters, such a splitter being depicted in Figure 4 with its strip 11a in the bifurcated form 40 of a Y.

By making the strip 11a with crenellated sides, as depicted at 50 in Figure 5, the characteristic impedance of the waveguide is provided with a periodic perturbation that provides spectrally selective Bragg reflection, usable for instance as a dispersion compensator.

The perturbations provided by the crenellations 50 can be augmented as depicted in Figure 6, by additional loading blocks 60 formed by depositing, patterning and then etching an additional silicon nitride layer deposited after the etching of the silicon layer 11. Alternatively the loading blocks can be employed in place of the crenellations to produce the required perturbations. Figures 5 and 6 specifically depict crenellations and loading blocks spaced with a uniform pitch, but it will be evident that the pitch may alternatively be graded in order to provide a chirped grating. Chirping may also be provided with a uniform pitch of crenellation and/or loading blocks by imposing this structure on a tapered strip 11a.

Another feature of these strip-loaded planar waveguides, made by the method discussed with particular reference to Figure 1, is that the upper surface of the guide layer is flat,and so is suitable for the deposition of an additional high refractive index material layer, for instance also of silica nitride, which can also be patterned by thin-film lithography. Material in this layer can be employed to couple light into the material from the guide layer, and from thence into material of a layer deposited on top of the additional high refractive index material. Such an arrangement is depicted in Figures 7 and 8, which respectively show a schematic plan view and longitudinal central section of a planar waveguide device in which light is coupled between first and second strip-loaded planar waveguides via an overlying waveguide. The first and second strip-loaded waveguides are respectively defined by strip loadings 70a and 70b formed in layer 11 of Figure 1 on substrate 10 and covered by guide layer 12. Formed, by thin-film lithography and selective etching, out of the additional high refractive index material layer to which previous reference has been made, are two generally lozenge-shaped regions 71a and 71b. Light launched into the strip-loaded guide defined by strip-loading 70a is coupled out of the guide

layer and into region 71a by the combined effects of the left-hand adiabatic taper of region 71a, the adiabatic taper 72a of strip-loading 70a, and the fact that the additional layer from which regions 71a and 71b are created is somewhat thicker than the layer 11 from which strip-loadings 70a and 70b are created.

Formed, by thin-film lithography and selective etching, out of the material of the layer deposited upon the regions 71a and 71b, is a generally lozenge-shaped region 73. The material of this region 73 has a refractive index intermediate that of the guide layer 12 and that of the regions 71a and 71b, and so the light previously coupled into region 71a is then coupled into region 73 by the combined effects of the right-hand adiabatic taper of region 73. The symmetry of the structure then ensures that the light coupled into region 73 is coupled via region 71b into the strip-loaded waveguide defined by strip-loading 70b. The intermediate refractive index material of region 73 may for instance be an optically amplifying material such as silica co-doped with erbium and alumina.

CLAIMS:

1. A strip-loaded optical waveguide device having a substantially planar dielectric guide layer on one major surface of which is provided one or more waveguide defining loading strips of low profile compared with the thickness of the guide layer and of higher refractive index than that of the guide layer, wherein the two major surfaces of the guide layer, together with the or each loading strip, are bounded by dielectric material of lower refractive index than that of the guide layer.

2. A strip-loaded optical waveguide device as claimed in claim 1 wherein the or each loading strip is made of silicon nitride.

3. A method of making a strip-loaded optical waveguide device including the steps of;

coating a major surface of a dielectric substrate layer with a waveguide configuration defining layer;

patterning said waveguide configuration defining layer and removing portions thereof to define one or more substantially isolated strips of material of the waveguide configuration defining layer;

coating the strip-coated surface of the substrate layer with a dielectric guide layer; and

coating the guide layer with a dielectric cladding layer;

wherein the thickness of the waveguide configuration defining layer is small compared with the thickness of the guide layer; and

wherein the refractive index of this waveguide configuration defining layer is greater than that of the guide layer which, in turn, is greater than that of both the substrate layer and the cladding layer.

4. A method of making a strip-loaded optical waveguide device including the steps of;

coating a major surface of a dielectric substrate layer with a dielectric guide layer;

coating the guide layer with a waveguide configuration defining layer;

patterning said waveguide configuration defining layer and removing portions thereof to define one or more substantially isolated strips of material of the waveguide configuration defining layer; and

coating the guide layer and its one or more strips with a dielectric cladding layer;

wherein the thickness of the waveguide configuration defining layer is small compared with the thickness of the guide layer; and

wherein the refractive index of the waveguide configuration defining layer is greater than that of the guide layer which, in turn is greater than that of both the substrate layer and the cladding layer.

5. A strip-loaded optical waveguide device made by the method claimed in claim 3 or claim 4.

6. A strip-loaded optical waveguide device as claimed in claim 1, 2 or 5, which device includes at least one tapered strip-loaded optical waveguide.

7. A strip-loaded optical waveguide device as claimed in claim 1, 2, 5 or 6, which device includes at least one Y-junction strip-loaded optical waveguide.

8. A strip-loaded optical waveguide device as claimed in claim 1, 2, 5, 6 or 7, which device includes at least one laterally crenellated strip-loaded optical waveguide.

9. A strip-loaded optical waveguide device as claimed in claim 1, 2, 5, 6, 7 or 8, which device includes at least one strip-loaded optical waveguide the thickness of whose strip-loading is spatially modulated in the axial direction of the strip-loading.

10. A strip-loaded optical waveguide device as claimed in claim 1, 2, 5, 6, 7, 8 or 9, which device includes first and second strip loaded optical waveguides that are optically coupled via an overlying waveguide.

11. A strip-loaded optical waveguide device as claimed in claim 10, wherein the overlying waveguide consists of or contains an optically amplifying medium.

12. A method of making a strip-loaded optical waveguide device substantially as hereinbefore described with reference to the accompanying drawings.

13. A strip-loaded optical waveguide device made by the method claimed in claim 12.

Patents Act 1977 13 **Examiner's report to the Comptroller under Section 17 (The Search report)**	Application number GB 9521158.7
Relevant Technical Fields (i) UK Cl (Ed.N) G2J (JGDA, JGDB) (ii) Int Cl (Ed.6) G02B	Search Examiner MR C ROSS Date of completion of Search 16 NOVEMBER 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii)	Documents considered relevant following a search in respect of Claims :- 1-13

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	WO 91/10931 A1	(BT)	1 at least
X	US 5134681	(THOMSON) see especially Figures 7, 8	1,3,4 at least

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).